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DSTO-TR-1378

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ABSTRACT

In order to support its continuous modernisation process, the Australian Army requires analytical support in determining the effectiveness of their conceptual Enhanced Combat Force (set fifteen years ahead). Central to this is how new and emerging technologies might impact on how the land force operates, and, consequentially, how the Army's operational concepts might need to change. Agent Based Distillations (ABD) have been employed to analyse a problem based on Manoeuvre Operations in a Littoral Environment concept. Specifically, the hypothesis tested was whether a small, mobile force with high situational awareness coupled with effective reach-back munitions could defeat a significantly larger force. This paper illustrates the application of one such ABD, EINSTein, in support of the analysis of this hypothesis, and highlights the potential utility of ABDs for land operations analyses.

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Executive Summary

This research has been driven by the need for modelling approaches which address the issues of emergent behaviour that arises from interactions of combatants in the battlespace. In doing so, it provides the capacity to support the development and analysis of new warfighting concepts. Explorations of these concepts require short turn-around times; including developing the scenarios, coding the model into a simulation tool, running the model and data exploration. The catalysts for our investigations were:

- the Army Headline experiments, an annual series of experiments designed to support concept and capability development for the Australian Army, and
- Project Albert, a United States Marine Corps research effort aimed at investigating the intangible factors of combat that impact on a commander's decision process.

This paper describes the results of a case study we used to explore a force mix problem within the concept of Manoeuvre Operations in a Littoral Environment (MOLE). To experiment with Agent Based Distillations (ABD) we abstracted a problem based on the MOLE concept. The specific hypothesis tested was whether a small, mobile force with high situational awareness coupled with effective reach-back munitions could defeat a significantly larger force. The case study produced a number of useful initial insights into the force mix problem. The analysis by ABD allowed the contributions of the Armed Reconnaissance Helicopters and High Mobility Artillery Rocket System assets to mission success to be quantified and traded off quite quickly. Synergies among platform and weapon characteristics were also identified; it was found that sensor range and lethality act quite strongly together. The implication is that investments in weapon and platform upgrades might be best considered jointly rather than in isolation. However, it is important to stress that the results of a distillation merely provide some potential directions for further study, which may or may not prove the assertion to be valid.

This study and other case studies illustrate the potential ABDs have for distilling a problem into the essential elements of the analysis. Extensive parameter excursions can be conducted in a timely manner on desktop computers, ranging from a few hours for indicative (coarse grained) results, to running overnight if more reliable statistics are required. This is in stark contrast with traditional wargames whose timescales are measured typically in units of weeks or months.

Authors

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Andrew Gill graduated from James Cook University of North Queensland with a BSc majoring in Mathematics in 1991 and a PhD in Applied Mathematics in 1995. He has worked as an Associate Lecturer in the Applied Mathematics Department at Adelaide University. He started work at Land Operations Division, DSTO, in June 1998 in the operational analysis of Land Force capabilities, particularly the development of system concepts for rapid landmine route clearance.

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Richard Egudo obtained his MSc in Operational Research from London School of Economics and a PhD from LaTrobe University. His academic career has included lecturing and research at Makerere University, Papua New Guinea University of Technology, Florida State University and Monash University. He joined DSTO in 1999 and was subsequently posted to the Australian Army's Combined Arms Training and Development Centre in Puckapunyal to provide support to their capability development activities. He returned to DSTO Edinburgh in 2002 and is now working on the Army Experimental Framework analysis task. He has published articles in international journals on mathematical programming and internet ATM data analysis and management.

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Peter Dortmans obtained a PhD in Theoretical Physics at the University of Melbourne in 1992 and undertook post-doctoral research at the University of Melbourne and the Instituto Nazionale di Fisica Nucleare in Padova (Italy). He joined DSTO in 1999 and was subsequently posted to the Australian Army's Combined Arms Training and Development Centre in Puckapunyal to provide support to their capability development activities. Upon his return to DSTO Edinburgh in 2002, his work focus shifted to supporting future concepts development.

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Contents

Glossary

ABCA	America Britain Canada and Australia
ABD	Agent Based Distillation
AEF	Army Experimental Framework
AO	area of operations
ARH	armed reconnaissance helicopter
CATDC	Combined Arms Training and Development Centre
CNA	Center for Naval Analysis
DOTSE	Defence Operational Technology Support Establishment
DSTO	Defence Science and Technology Organisation
DTA	Defence Technology Agency
EINSTein	Enhanced ISAAC Neural Simulation Toolkit
HE	Headline Experiment
HIMARS	high mobility artillery rocket system
ISAAC	Irreducible Semi-Autonomous Adaptive Combat
ISC	inter-squad connectivity
ISTAR	intelligence surveillance target acquisition and reconnaissance
LAV	light armoured vehicle
LER	loss exchange ratio
MANA	Map Aware Non-uniform Automata
MCCDC	Marine Corps Combat Development Command
MOE	measure of effectiveness
MOLE	manoeuvre operations in a littoral environment
RTA	Restructuring the Army
USMC	United States Marine Corps

1. Introduction

In order to develop a "dynamic and evolutionary" war-fighting capability and in response to the Revolution in Military Affairs, the Australian Army initiated a process for remodelling the Army. This process, known as Restructuring the Army (RTA), would both enhance its current capacity to meet its strategic requirements and provide direction for the migration to an enhanced future combat force. The RTA field trials commenced in 1997, in order to analyse, develop and enhance capabilities and processes, and provide evidence to inform decisions on the types of capabilities Australia should invest in, in the medium to long term [1].

A central component of this methodology was the Battlelab Process [1, 2], which focused on modelling systems, testing them in the field and then analysing those results in order to inform capability development decisions. This process was further refined and embedded within the Army Experimental Framework (AEF) [2], which provided a six-step process for military experimentation. The RTA trials were underpinned by a vision based on the manoeuvre concept, that is, an integrated modern highly mobile task force and units capable of effective autonomous operations of widely dispersed and dynamic nature in both joint and combined theatres.

The most difficult, resource intensive and time-consuming phase of RTA was the field trials conducted in 1998. Other commitments meant that the level of military resources required for the RTA trials could not be sustained in subsequent years. In addition, there was a limited capacity for future concepts and capabilities to be considered using a current force trained to fight within the constraints of current doctrine. Therefore the major RTA Phase 2 experiment (Headline Experiment 1999 (HE99)) utilised seminars and wargames rather than field trials.

HE99 focused on determining the impact of varying levels of situational awareness on an austere, highly mobile but organically firepower-poor force fighting in open terrain. The HE99 experiment itself involved considerable effort from both the defence and scientific communities in the design, conduct and analysis of the two-week experiment.

The results from the Headline seminars and wargames were later fed into higher resolution wargames and closed loop simulations. Coding the scenarios took approximately three months, so the preliminary analysis results from these models became available six months after HE99 was completed. However, as AEF activities are an annual event, planning for HE00 was already underway, so that some opportunities for further refinement of the concepts were missed.

2. Agent Based Distillations

The preceding section highlights the high resource and time requirements that current land combat analysis tools require in providing results to inform capability development decisions. Lauren and Baigent [4] also outlined other difficulties traditional wargames and simulations have with analysing land-force issues, which has led them to investigate alternative models under the Project Albert research program.

2.1 Project Albert and Australia's involvement

Project Albert is a United States Marine Corps (USMC) research effort aimed at investigating the intangible factors of combat that impact on a commander's decision process. Project Albert attempts to assess the general applicability of the concept of 'Operational Synthesis' [5], which brings together all of the factors, both tangible and intangible, that may impact on a commander's plan.

Project Albert aims to identify emergent behaviour through the application of a bottom-up approach rather than the traditional top-down approach, and seeks to address three key areas:

- non-linear behaviour (whereby small changes create disproportionate responses),
- co-evolving landscapes (which characterise the changing battlefield); and
- intangibles (such as morale, discipline and training);

which conventional land combat analysis models are particularly poor at investigating.

Project Albert was introduced to the Defence Science and Technology Organisation (DSTO) through the America Britain Canada and Australia (ABCA) Armies Standardisation Program, and to the Combined Arms Training and Development Centre (CATDC) during HE99 by the New Zealand ABCA representative.

The NZ Defence Technology Agency (DTA, formerly the Defence Operational Technology Support Establishment (DOTSE)) demonstrated how they were employing the tools within Project Albert to assist in restructuring their combat force. It was recognised that the AEF could benefit from using the tools to investigate the very issues that Project Albert was attempting to explore. Hence Army and DSTO have subsequently become collaborators within the Project Albert research program.

2.2 Agent Based Distillations

Agent Based Distillations (ABD) are low-resolution abstract models, used to explore questions associated with land combat operations in a short period of time. Being Agent based models means that only simple behavioural rules need to be assigned. This is generally achieved by assigning 'personalities' to the agents by way of relative weightings

to various elements on the battlefield (friendly and enemy agents, notional 'flags', terrain features, etc) and a penalty function to determine the entity's next move. Various 'meta-personalities' can also be assigned which moderate the agent's default personality if certain threshold constraints are exceeded from time to time.

Thus the scenario is generally much less scripted than that required of traditional wargames, the idea being that higher-level behavior is allowed to develop, or emerge, from the dynamic local interaction of the entities on the battlefield. This approach allows greater freedom of action within the scenario, which appears to be suitable for more modern operations based on manoeuvre concepts.

Being deliberately low-resolution means that the detailed physics of combat are largely ignored (or abstracted to simple constructs). Typically this involves assigning simple numerical values for characteristics such as speed, sensor, communication and weapon ranges, lethality and vulnerability. This allows a focusing of thought on the essential elements of the analysis, which typically is the dynamic interaction of entities on the battlefield.

These two characteristics mean that advances in computing power can be exploited to produce a significant volume of data. This process is known as data farming [6] and allows extensive parameter excursions to be performed, both in terms of variations in platform capabilities (physical characteristics) and tactics (behavioural characteristics), from the baseline scenario. This then enables one-way and two-way sensitivity analyses to be performed to explore any emergent behaviour and synergies in the system. The farmed data can also be used to perform statistical analyses to test the significance of the properties observed.

This is in stark contrast to traditional wargames whose timescales are measured typically in units of weeks or months. The trade-off to these desirable properties is that modelling resolution using ABDs is sacrificed. Thus the level of abstraction implies that the results of a distillation should only be used to provide a focusing of ideas and that subsequent analyses be conducted to 'drill-down' with higher resolution modelling. This provides another set of tools in the Battlelab process used within the AEF [2] and also satisfies the principles of Operational Synthesis [5].

There are a growing number of ABDs being used under the Project Albert research program. The first model produced was the Irreducible Semi-Autonomous Adaptive Combat (ISAAC) model [7], which was produced for the US Marine Corps Combat Development Command (MCCDC) as a proof of concept model. An extension of this original model, incorporating a range of additional features and functionality, was developed at the Center for Naval Analysis (CNA) soon after and is known as the Enhanced ISAAC Neural Simulation Toolkit (EINSTein) [7].

The NZ DTA has recently developed an ABD, the Map Aware Non-uniform Automata (MANA), to support their studies [8]. MANA is largely based on ISAAC but has

incorporated two additional features. One is the increased number of states that entities can be in together with trigger mechanisms to transit between these states. The other is a memory map, which displays locations of detected entities, which dynamically fade.

There are also several other ABDs in various stages of development both in the US and in Australia, but these will not be discussed in this paper.

3. The Case Study

HE99 was designed to provide information addressing the combat effectiveness of an Enhanced Combat Force in a 2015 timeframe. One of the main questions to be answered was "Does EXFOR's manoeuvre concept allow it to win?" [3]. To experiment with ABDs we abstracted a problem based on Manoeuvre Operations in a Littoral Environment (MOLE) and the specific hypothesis to be tested was whether a small, mobile force with high situational awareness coupled with effective reach-back munitions could defeat a significantly larger force.

A 3-day workshop investigated this proposition employing the EINSTein [7] distillation to facilitate the study. The workshop had three aims. First, a number of baseline scenarios were to be constructed which modelled the units and mission as accurately as possible. As a result of this process, two subsequent aims should also have been achieved. They are: to determine some of the limits of applicability and resolution of the EINSTein distillation in modelling or representing Army capabilities and missions, and to develop within the CATDC-DSTO group an increased level of proficiency in the use of ABDs.

3.1 MOLE scenario overview

A broad description of the main elements of the scenario is given below, and the main physical characteristics of each element are presented in Table 1. More detail can be found in Appendix A. The Blue force consists of a mix of light armoured vehicles (LAV), armed reconnaissance helicopters (ARH) and High Mobility Artillery Rocket System (HIMARS). For the baseline scenario, the force mix is such that there are 10 LAV, 5 ARH and 1 HIMARS unit. The Red force consists entirely of tanks (T-80), and for the baseline scenario there are 45 T-80s. Thus, the Red to Blue force ratio is approximately 3:1 for the baseline scenario.

Table 1: Major physical characteristics of scenario elements

	LAV	ARH	HIMARS	T-80	Red Capability
Movement	2	4		1	½ speed of LAV, ¼ of ARH
Sensor Range	4	8		2	½ sensor of LAV, ¼ of ARH
Fire Range	2	4		2	same range as LAV, ½ of ARH
Lethality	0.25	0.5	0.75	0.5	x 2 lethality of LAV, same as ARH
Number	10	5	1	45	3:1 ratio

It is important to make clear that the use of existing physical assets such as LAV and T-80 is for convenience only. The representation of these entities within the distillation is at such an abstracted level (low resolution) that it would be better to refer to the entities, such as the T-80, as "a slow moving, relatively lethal, armoured ground based vehicle – possibly similar to a tank". Similarly, the values used in Table 1 are not meant to represent absolute values and should be viewed relatively, as indicated in the final column.

The LAV have relatively good speed and sensor range, but relatively poorer weapon characteristics. The task for the LAV is to survey the likely approaches of the enemy and to communicate detections back to the ARH and HIMARS units for prosecution.

The ARH are significantly faster than the LAV and have double their sensor and weapon performance, however there are fewer of these assets. The task for the ARH is to quickly move to the location of detected enemy and decisively engage, based on the communicated information supplied by the LAV.

The HIMARS unit is a single asset held at the rear of operations and brings heavy, lethal area fire onto regions of detected enemy supplied by the LAV. The T-80 have half the movement and sensor characteristics of the opposing LAV, but have double the weapon performance and outnumber the LAV 4.5:1.

3.2 Entity definitions

Some time was spent determining how each entity type could be best modelled in EINSTein. Appendix A summarises the key assumptions and limitations as well as suggesting some features that were not used in this case study but which may be of future use.

Figure 1 illustrates the relative simplicity in defining entities within EINSTein. The example shown here is for the LAV units. The column on the left defines the physical performance characteristics of the entity (sensor, weapons, movement, force size) as described in Table 1. The second column assigns a personality profile to the entity. The proper choice of relative weightings in this column allows one to define the behavioural characteristics of the LAV.

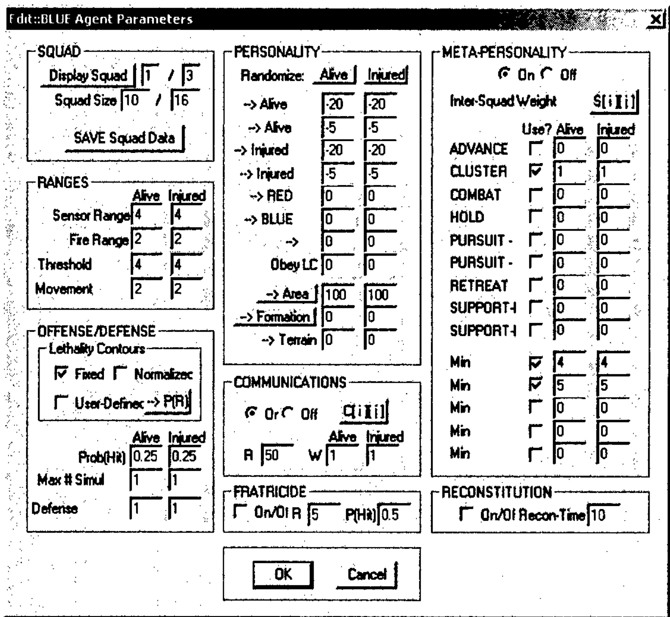

Figure 1: Example EINSTein entity definition

For example, to simulate reconnaissance behaviour, 'negative attractiveness' to friendly and enemy entities is used. The former is used to create a dispersed reconnaissance force, while the latter is used to ensure the LAV do not become decisively engaged. A high attractiveness to the Area entity is used to simulate an area of operations (AO) assigned to the LAV force.

The final column is used to simulate exceptions or extensions to the default personality defined by the second column. For example, the Cluster 'meta-personality' is used to further enhance the dispersed nature of the LAV force, as are the Minimum distance to friendly and enemy parameters.

Similar entity definitions can then be constructed for the other units (ARH, HIMARS, T-80) to simulate the required characteristics and behaviours. These are provided in Appendix B. There are also dialogue boxes to fill out to define the size of the battlefield and the initial locations of the combatants as well as to indicate what data to collect for analysis.

3.3 High Mobility Artillery Rocket System modelling

Of all the entity types being modelled, the HIMARS proved the most difficult to represent. EINSTein does not explicitly model indirect and/or area fire weapons (e.g. artillery). The closest approximation was to assign a grenade weapon to a HIMARS squad consisting of a single entity. Figure 2 displays schematically the modelling involved.

This includes a minimum and maximum throwing range, aim accuracy, blast radius, and probability of kill with distance. The sensor range should be at least as large as the

maximum throwing range. The decision on where to throw is determined by the maximum number of friendly and minimum number of enemy entities within the blast range. This may also allow investigation of whether to expend a round on a single enemy or wait until a few are within range.

The limitations inherent to this modelling are that the maximum throwing range is hard wired to 15 (therefore one may have to use a larger grid to get realistic HIMARS ranges) and that the HIMARS fall of shot is not called in by a forward observer.

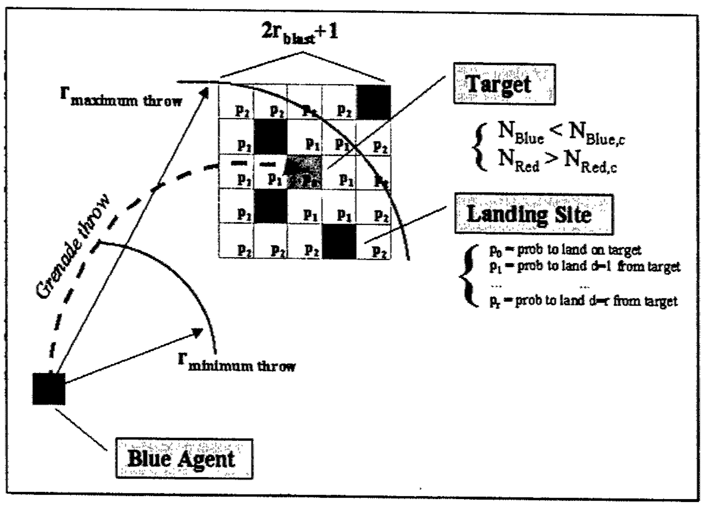

Figure 2: Grenade modelling in EINSTein

For a maximum throwing range greater than 15, one would need to use the normal point-to-point weapons. The best way to model this is to define the lethality contours to have a lethality probability of zero at ranges less than a minimum and greater than a maximum (like the throwing ranges above), and to have a contour (or constant) within them. Unless the maximum number of simultaneous targets is also set to one, you may get the HIMARS killing entities within an arc of 360 degrees (since everything within the firing range is a potential target).

To simulate the forward observer concept, we assigned a grenade weapon to the HIMARS entities. To allow effective reach-back capability the HIMARS was given a low sensor range and a high movement range to allow it to quickly react to communicated information. That is, the HIMARS would actually move quickly to where the target was and when it was within its limited throwing range it would fire a munition. When no enemy agents were present in its sensor range and no information was being received from the forward observers, it would then quickly retreat to its initial position.

The problem with this representation is that enemy agents would react to the HIMARS when it was in their sensor range. Ideally the HIMARS unit would be assigned a

detectability of zero, though this was found to be unachievable with EINSTein (due to problems associated with the terrain modifier features). To ensure the HIMARS unit wasn't destroyed by the Red force while within its sensor range, a large defence measure was assigned to the HIMARS unit, practically making it invincible. Ideally the HIMARS would be located stationary at the rear but it was hoped that the high movement range and ability of the HIMARS to advance and retreat so quickly would minimise this unwanted behaviour.

The grenade weapon parameters used for the HIMARS are shown in Figure 3. You will notice that the Probability of Hit may seem relatively low (0.4 as compared to 0.5 for the Red tanks). Another feature that cannot be modeled directly in EINSTein is a time lag between rounds fired. A weapon such as HIMARS requires a non-insignificant time between rounds to reload and acquire a target. It was found that a high Probability of Hit value for HIMARS was too lethal, and that the lower value of 0.4 provided more realistic behaviour and could be viewed as a form of time delay between rounds.

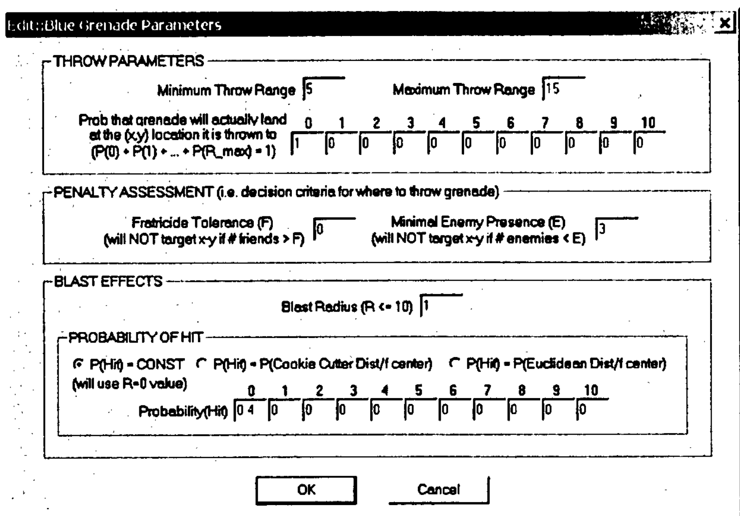

Figure 3: Grenade parameters for HIMARS

4. Simulation Run Modes

4.1 Interactive playback mode

EINSTein can be run under a number of simulation modes. The first that should be performed is the Interactive Playback mode. This enables the analyst to examine the behaviour of the entities, which should be correlated with their desired characteristics and

tasks. A degree of finetuning of the entity parameters is generally required to produce a baseline scenario with all entities functioning in a representative and consistent way.

However, one should try to avoid tweaking the parameters unnecessarily in an effort to produce the 'correct behaviour', that is, to produce scripted behaviour. The central point of ABDs is that we endeavor to seek emergent behaviour from the local interaction rules we define – not to constrain that behaviour.

Once the finetuning has been performed and a baseline scenario constructed, the Interactive Playback mode allows the analyst to obtain qualitative information about the force mix dynamic interactions. For the baseline scenario, Figure 4 displays snapshots at various times of the simulation. The Red force is situated to the east, represented by the red circles. The Blue LAV squad is near the centre, represented by blue circles. The Blue ARH squad is to the west of the LAV squad and is represented by green squares. The Blue HIMARS unit is the dark circle located below the Blue flag (black square) to the far west. Small squares represent locations of Blue kills, while the crosses represent locations of Red kills.

For our baseline scenario, we note that Red travels tightly grouped from East to West through the area of operations (AO) patrolled by the LAV squad. The LAV, due to their superior sensors and speed, detect the incoming T-80 and communicate these detections back to the waiting ARH and HIMARS. From the ensuing engagements we note that most LAV manage to avoid decisive engagement with the T-80 and generally survive. The Red force is heavily attrited, mainly by the ARH and HIMARS and only a few Red manage to reach the objective (represented by the Blue flag).

Thus for the baseline scenario, at least on a qualitative level, it is not impossible for a smaller, more mobile force with high situational awareness and effective reach-back munitions to defeat a much larger opposing force. The question that arises is what is the relative contribution to this success of different force mixes and varying asset characteristics.

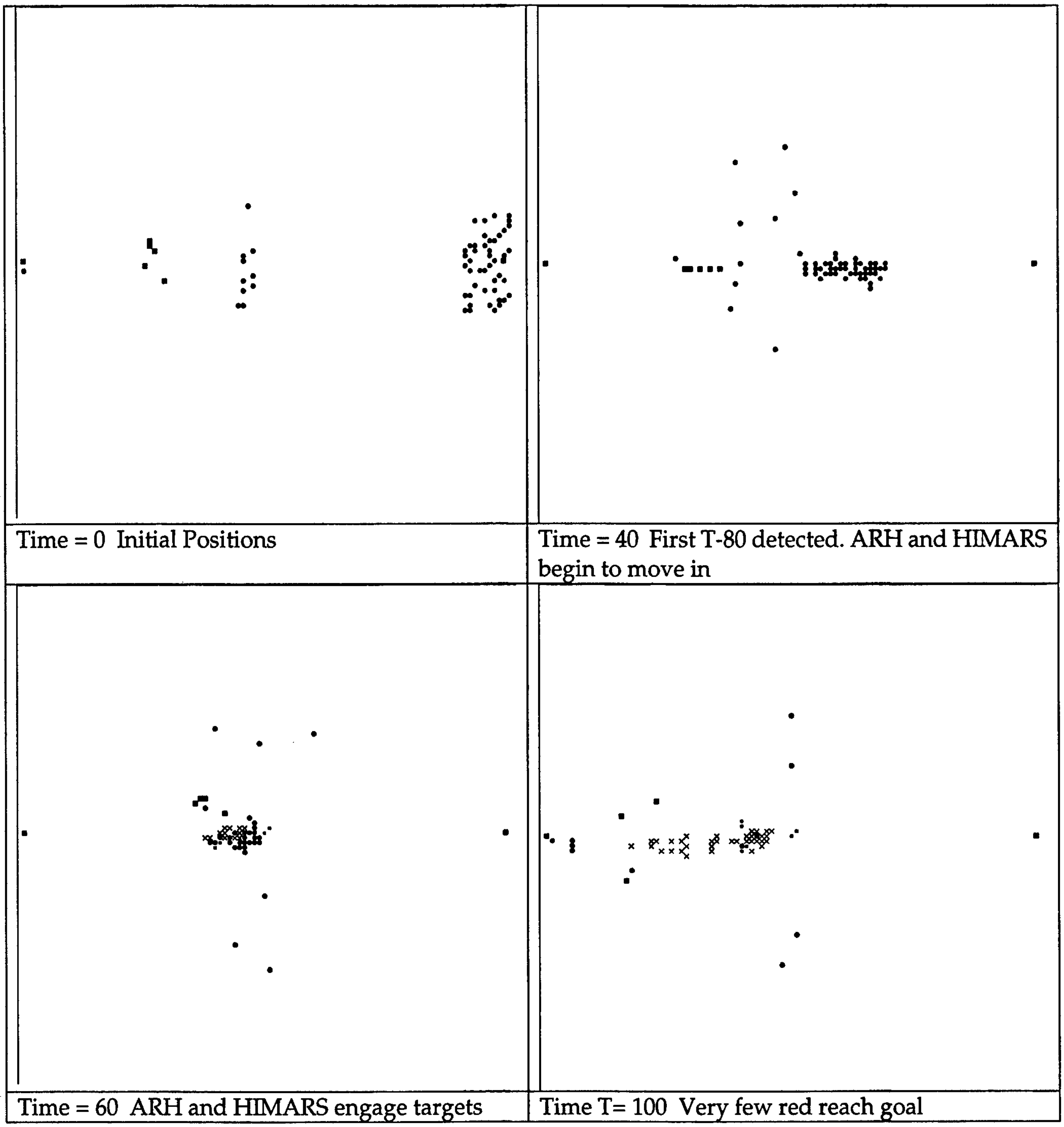

Figure 4: Snapshots of baseline scenario simulation

4.2 One way sensitivity analysis mode

Having performed a qualitative level analysis of the scenario and hypothesis, the next run mode to use is the multiple time-series data collection mode. This is essentially a one-way sensitivity analysis from the baseline scenario, which allows the relative effects of individual parameters on the mission to be quantified.

As an example of this parameter excursion, we investigated the effect of different force mixes (in terms of the number of ARH and whether or not HIMARS was available) on the success rate of the Red force. The measure of effectiveness (MOE) used was the percentage of Red forces that manage to reach the objective (Blue flag).

Figure 5 shows the variation of this MOE with different numbers of ARH – the upper curve represents the situation with no HIMARS while the lower curve is the case with a single HIMARS unit. With no HIMARS and no ARH the Red force easily achieves its mission, with all entities reaching the objective. With a single HIMARS and no ARH just over half of the Red force now manage to reach the objective. In both cases, as the number of ARH is increased Red mission success is diminished.

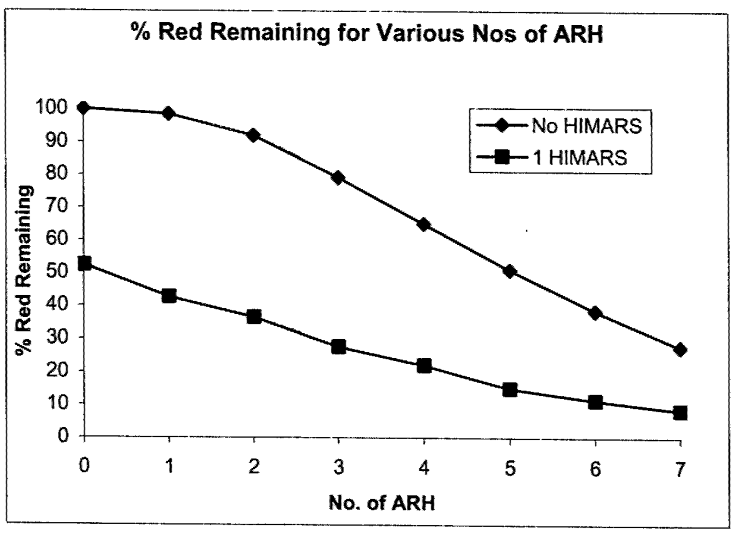

Figure 5: Effect of number of ARH on red success

In both cases, there is some non-linearity in this reduction, although it is not strong. In the case of no HIMARS, it appears that at least two ARH are required to significantly affect Red's mission. Also, in the case with HIMARS, there appears to be diminishing returns as more and more ARH are added to the force mix. This may suggest that there is an upper limit of ARH that a cost-effective Blue force mix should possess.

We can also use this graph to start to make broad capability comparisons. For example, the data indicates that to ensure that only 50% of the Red force achieves their objective, this

effect could be equally generated with either one HIMARS or six ARH. Similarly, to ensure that only 30% of the Red force achieves their objective, this effect could be equally generated with either one HIMARS with four ARH or eight ARH. Note that this second result does not scale linearly with the first (which would suggest that one HIMARS with four ARH is equivalent to ten ARH). This type of force mix trade-off analysis could be useful in supporting acquisition decisions once the relative costs of assets are taken into account.

4.3 Fitness landscape mode

The third run mode available is the 3D data collection mode, also known as the Fitness Landscape mode. Essentially, this is a 2D sensitivity analysis and the surface plotted shows the variation of the selected MOE with two user-specified parameters, which is a useful mechanism to detect allowable trade-offs (essentially contour lines of the plotted surface) as well as synergies between parameters.

Figure 6 shows the variation of the "Red to Blue" Survival Ratio (a complement to the usual loss exchange ratio (LER)) as the size of the Red force changes (ranging from 30 to 120) and changes in the level of dispersion of the Red entities (ranging from low to high). The latter was modelled by using the Minimum Distance to Friendly meta-personality. Higher values of the MOE indicate improved Red mission success.

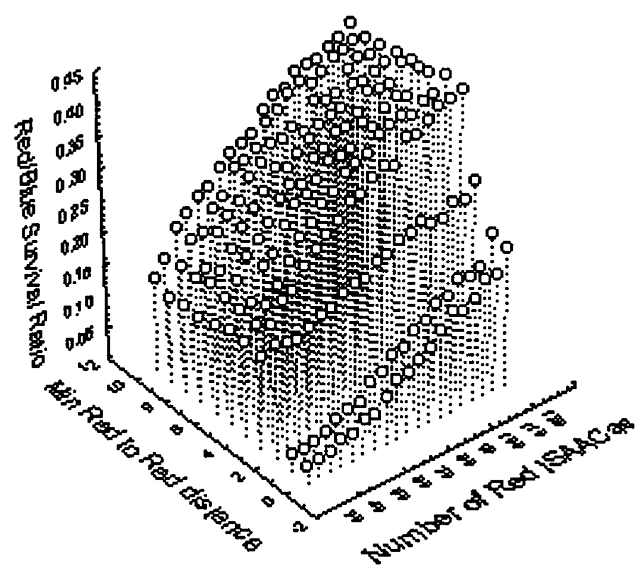

Figure 6: Fitness landscape of Red effectiveness with variations to Red Force size and Red dispersion level

If we take slices of the surface for different dispersion levels, the shape of the curve is roughly linear with the number of Red forces. Thus, combat weight for Red appears to have a linear effect on success. The surface also clearly shows a marked improvement for Red once a dispersion level greater than one is achieved. For dispersion levels greater than three, for a fixed force size, there is no noticeable improvement. Thus, the optimum dispersion level appears to be roughly three.

An investigation as to the cause of this result can be made by running several Interactive Playback sessions, which reveal that the reason is related to the means of employment of the HIMARS. As HIMARS is a limited resource, thresholds were imposed such that delivery of a HIMARS round required a minimum number of enemy targets within a given range and a maximum number of friendly entities (to reduce fratricide). Thus, once Red dispersed to a certain level, it effectively provided Blue with no sufficiently massed target to afford a HIMARS strike by remaining below its engagement threshold.

This result immediately suggests a range of 'what-if' scenarios and measure-counter measure issues and ABDs can be used to explore these issues. As mentioned above, this Fitness Landscape analysis can allow trade-offs to be explored. For example, it might be possible for Red to use a smaller but more dispersed force and achieve the same level of mission success. Figure 7 below displays the Fitness Landscape when varying the sensor range and probability of kill (lethality) of Red. Once again, if we examine slices of this landscape for fixed values of the sensor range, we see that the lethality of Red appears to have a linear effect on its mission success.

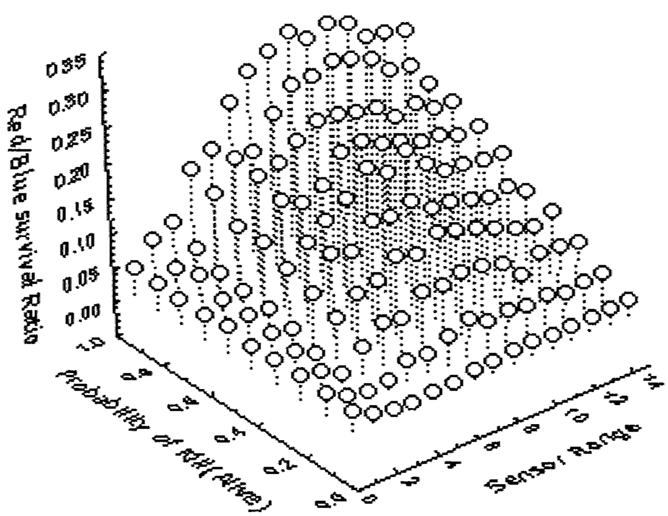

Figure 7: Fitness landscape of Red effectiveness with variations to Red sensor range and Red Probability of Kill

However, the interesting point to note is that the degree of linear effect (essentially the slope of the curve) is not constant but changes quite strongly as the sensor range of Red is increased. Initially this change is positive, whereby the effect of an increase in lethality from 0.4 to 0.6 (for example) is more pronounced with a sensor range of 6 than with a sensor range of 2. This illustrates the potential effect of synergy between platform characteristics.

Note also, however, that this behaviour does not occur for all values of the sensor range, and in fact a reversal of behaviour appears to occur once a sensor range of about 8 is exceeded. On further investigation (by using the Interactive Playback Mode) the cause for this behaviour was deduced.

The goal for the Red force is to reach the Blue objective (the flag) while attempting to minimise its own losses and maximise losses to the Blue force. The termination criteria used to stop the simulations and collect data on force losses was reaching a fixed time, which needs to be large enough to allow the mission to be played out. In most cases the Red force made its way to the objective where it then waited safely until the termination time was reached. However, in the cases where its sensor range was large, it could detect the Blue forces and was drawn back into battle and away from its objective, and suffered increased losses as a result.

Thus, this behaviour is unrealistic and unwanted and therefore the results for these cases should be discarded (essentially the portion of the landscape in Figure 6 for sensor ranges greater than eight). However this analysis is useful in highlighting the need to critically examine the data output and its relevance to the problem under investigation, and the Interactive Playback mode is a useful tool to achieve this.

One can also use these landscapes to trade off parameters, whereby for example the same effectiveness for Red is achieved with a sensor range of 2 and a probability of kill of 1 or a sensor range of 5 and a probability of kill of 0.4. One might suspect that the technological challenges of achieving such a high lethality in the former configuration are such that the latter solution might be more feasible.

A final trade-off analysis conducted for this scenario was that between the speed of the Red force tanks and the level of dispersion adopted. From the Interactive Playback runs, it is apparent that the casualties suffered by Red occur in the time taken to traverse from its starting position to the objective on the West side of the battlefield. If that time taken could be reduced, then Red would expect fewer losses on average.

Thus the situation considered was one of a choice for Red to conduct its movement either along a road or cross-country. The effect of road travel was to increase the speed of the tanks but at the expense of having to travel in a more grouped (or less dispersed) fashion. Cross-country travel was slower but could be performed at different levels of dispersion. Due to the limited number of movement speeds within EINSTein, the speed of on-road travel was taken to be twice that of the cross-country speed.

EINSTein was used to produce LER data under three situations – cross country with low dispersion; cross country with medium dispersion; and on road (therefore with no dispersion). Table 1 below displays the results generated. Note that a larger LER value corresponds to improved Red performance.

Table 2: Loss Exchange Ratio results for different modes of Red movement

	Low Dispersion	Medium Dispersion	On Road
Red Killed	91%	66%	68%
Blue Killed	27%	50%	26%
Loss Exchange Ratio	0.30	0.76	0.38

The results indicate that dispersed travel is preferable if travelling cross-country (which is essentially what the Fitness Landscape in Figure 5 above revealed), in that both Red losses are reduced and Blue casualties are increased and the LER is consequently more than doubled. The results also indicate that if travelling on road, then only the Red losses are reduced (by the same margin as dispersed cross country) but the Blue casualties are not affected. This is because of the decreased time Red has to engage the Blue LAV due to the increased speed on-road, and the decreased ability to hunt the Blue LAV due to being constrained to the road. Consequently there is only a marginal improvement in the LER.

Thus, if only the number of Red losses is important, then both tactics of cross-country dispersed or on-road travel are equally effective. However, if the LER is more important, then the results indicate that the tactic of cross-country dispersed travel would be preferable.

4.4 Case study observations

The case study analysed here produced a number of useful initial insights into the force mix problem. First, analysis by ABDs allowed the contributions of the ARH and HIMARS assets to mission success to be quickly quantified and traded off. The results suggested some regions of non-linearity (decreasing returns) for the ARH effectiveness. The results also highlighted the importance of tactical considerations employed by the Red force against area type or indirect weapons and the ABD used allowed various tactical options to be evaluated including cross-country or route movement decisions.

Fortunately the difficulties in modelling the HIMARS unit did not translate into any noticeable unwanted behaviour for this case study. The high defence measure and speed assigned to the HIMARS unit allowed it to perform its function safely and effectively, while the proportion of time the Red units were chasing a 'ghost' (the HIMARS unit) was minimal.

Synergies among platform or weapon characteristics, if they exist, are easily identified using the Fitness Landscape run-mode, and for the force mix problem it was found that sensor range and lethality act quite strongly together. The implication is that investments in weapon and platform upgrades might be best considered jointly rather than in isolation.

5. Conclusions

The workshop proved quite useful in making progress towards our goals of developing baseline scenarios, determining the bounds of applicability of EINSTein and developing a level of group competency in using ABDs. Some observations about each of these are presented below.

Indications are that ABDs have the potential for distilling a problem into the essential elements of the analysis. A lot of the detail can be omitted to leave only the relevant components for the study -- assuming these components can be modelled to the resolution required of the study. It is therefore obvious that a key characteristic of ABDs is their speed. For example, it is generally possible to create reasonable baseline scenarios within a day and have statistically reliable data over a range of parameter excursions the next day.

With the baseline scenarios constructed, parameter excursions can easily be conducted (either on PCs running overnight for more reliable statistics, or within about an hour for coarse-grained results). The relative effectiveness of force components can be estimated and compared, as can the trade-space of capability parameters. This is in stark contrast to traditional wargames whose timescales are measured typically in units of weeks or months.

Having said this, however, it was found that the EINSTein ABD did possess a number of undesirable characteristics. It became evident that the code is somewhat unstable, with crashes occurring relatively frequently. There was also some functionality that would have been very useful for the force mix hypothesis studied that was either unavailable or appeared to be available but did not function properly.

For example, the modelling of indirect fires (for HIMARS) is very limited in the current version of EINSTein, and some of the purported features associated with terrain did not function as described. Finally, there were some variables that would have been quite useful for modelling purposes if they were made squad specific, for example, communications range and the selection of targets and the associated lethality against that target.

Having said this however, the workshop did manage to achieve, to differing levels of success, the three aims outlined previously. Baseline scenarios could be constructed within a day – although some of the modelling was less accurate than we had initially hoped -

and as a group we quickly established an increased level of proficiency in using at least one ABD. The subsequent two days of the workshop then went a long way towards determining the limits of applicability of the EINSTein ABD.

It is important to stress that the results of a distillation merely provide some potential directions for further study, which may or may not prove to be useful (depending on the degree of abstraction required to 'fit' an ABD scenario). They do not provide quantitative 'answers'. Their usefulness, if proven to be true, lies in their ability to quickly provide a focusing of ideas for further higher resolution modelling (for example, in suggesting which factors appear to be important in subsequent wargaming).

The final point to make is that the list of instances of ABDs is growing, each with its own strengths and weaknesses. The key will be, as in any operations analysis, to select an appropriate instance or instances from this list of models that adequately addresses the problem in hand.

6. Acknowledgements

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Appendix A: Initial Evaluation of EINSTein Applicability

A.1. LAV characteristics

- Small number – OK.
- Forward position – can define initial locations of squads.
- High mobility – can use movement range (eg 2 vs 1 for T-80 vs 4 for ARH).
- Limited firepower – can use fire range (low); single-shot hit and kill probability (low); or number of simultaneous targets (low).
- Dispersed – can use the weighting towards alive/injured friendly (low or negative); cluster meta-personality (maximum number of friendly within a threshold range – low/high); or minimum distance to friendly meta-personality (minimum distance to any other single friendly entity -- high).
- Avoid contact – can use the weighting towards alive/injured enemy (low or negative); combat meta-personality (minimum relative strength advantage required to move towards enemy – high); or minimum distance to enemy meta-personality (minimum distance to any other single enemy entity -- high).

A.2. ARH characteristics

- Two or three pairs – can treat a pair as a single entity requiring two hits to be killed.
- Highly mobile – can use movement range (high).
- Good firepower -- can use fire range (high); single-shot hit and kill probability (high); or number of simultaneous targets (high).
- Limited resource – can use small number of entities.
- ISTAR to HIMARS – can switch on the entry in the inter-squad communications matrix, but this only provides the information in the ARH sensor range to the HIMARS in order to adjust the decision for the HIMARS next move (cannot be used to adjust his combat/firing). Better is to have a communications link between the ARH and the LAVs (probably going from LAV to ARH – ie LAVs detecting enemy, avoiding contact, but alerting ARH to enemy position).

A.3. HIMARS characteristics

- There is a small number of HIMARS– OK.
- Limited amount of munitions – could possibly model this by using the number of hits to be killed as a counter and to have fratricide of 100% within a radius of one (so that each firing from the HIMARS also hits itself). Limitation then becomes Red not being able to kill the HIMARS properly.
- Stationary at the back – can use movement range (zero) and pre-position the HIMARS squad.
- Other modelling limitations are discussed explicitly in the main text of this paper.

A.4. T-80 characteristics

- Large number – OK.
- Forward position – can define initial locations of squads.
- Limited mobility – can use movement range (eg 1 vs 2 for LAV vs 4 for ARH).
- Good firepower – can use fire range (medium); single-shot hit and kill probability (medium); or number of simultaneous targets (medium).
- Aggressive -- can use the weighting towards alive/injured enemy (high); combat meta-personality (minimum relative strength advantage required to move towards enemy – negative).
- Attack in numbers, if possible – can obtain this if you turn on communications between the T-80s so that a group of T-80s will be attracted to detected enemy.
- Limited communications among themselves – contrary to the 'attack in numbers', but can be modelled with the communications range (low) or communications weights (low).
- Divided into specific troops – can be modelled using multiple squads with identical characteristics each representing a troop.

A.5. Additional EINSTein features that may be useful

- Inter-squad connectivity (ISC) matrix – normally entities consider all friendly entities within its sensor range as equals in determining its next move. The ISC matrix allows the LAV squad to ignore (either completely or on a proportional basis) the ARH (and HIMARS if within sensor range) in deciding its next move.

- Local/Global Commander – since there are a large number of T-80s, the use of a local commander to coordinate the movement of elements under its command to control the battlefield within the command radius may be useful. Essentially, the local commander can be used to direct entities to move towards a region where some T-80s are outnumbered by the enemy. The local commander could be at the highest level, or at the squad level if the T-80s are partitioned into troops. In the latter case, a global commander could be added to coordinate the movement of each of the local commanders.

- Terrain and terrain specific modifiers – a few types of terrain (degrees of passibility) can be added to the battlefield and the characteristics of entities may be modified if located on these terrains. Their use may be to model different mobility characteristics (track vs wheeled depending on terrain) or detection characteristics (there is a P detect parameter on terrain, whereas normally everything within the sensor range is detected).

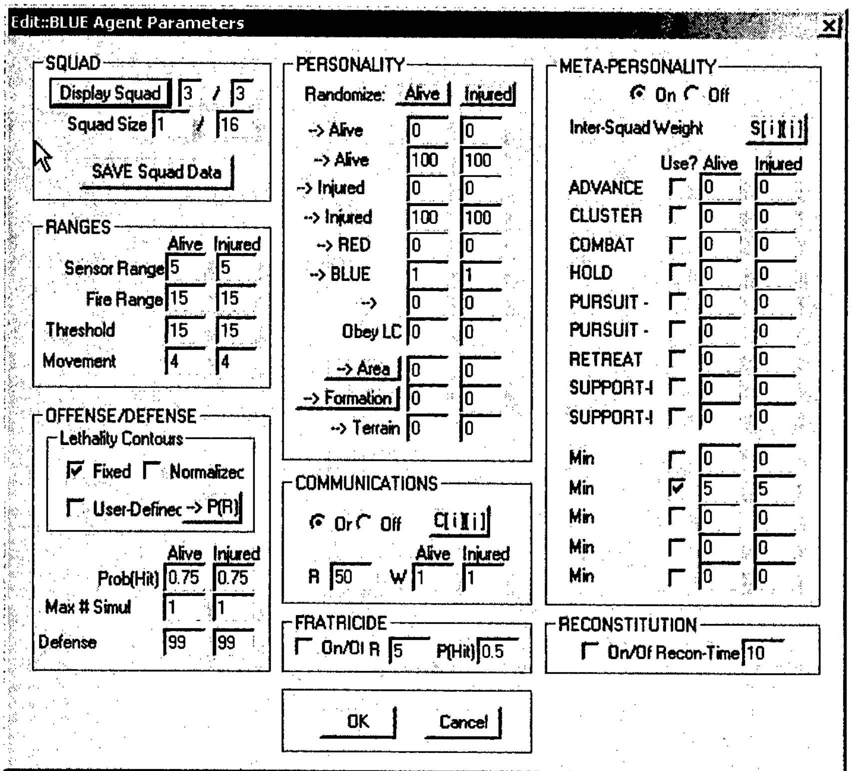
A.6. EINSTein current limitations

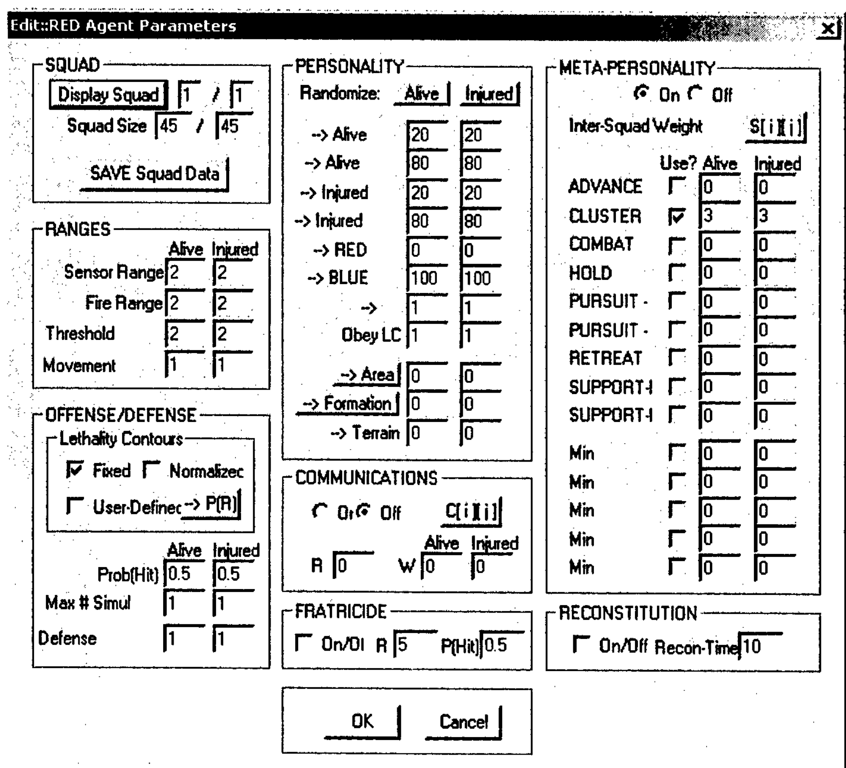
- EINSTein does not model area weapons particularly well, but they can be approximated using grenades, and it does not model them with remote targeting at all.
- EINSTein does not explicitly model a weapon store, but this can be approximated using fratricide and the defence parameter, although this would not be good if the enemy has a chance of killing the weapon before using all its munitions.
- EINSTein does not explicitly model target specific kill probabilities, but this can be approximated using the Pkill and defence parameters.
- EINSTein does not model the hunting of specific targets in terms of movement selection at all, for example, T-80 hunting LAV only and ignoring ARH entities within its sensor range.
- Exactly one entity is permitted to occupy a cell and all entities have the same size (size of a cell).

A.7. Modelling strategy

- LAV and T-80 entities roaming around the forward positions – LAVs working like recon (and palming off to ARH) while T-80s hunting.
- ARH flying around either forward (to hunt or to recon and palm off to LAV (unlikely)) or rearward protecting the HIMARS positions and waiting to be called forward from the LAVs.
- HIMARS not static but are within communications range of either the LAVs or ARH (depending on which is providing the recon function) and move based on this information. The idea is that time movement will bring the HIMARS effective firing range over the position of enemy units, thus approximating the 'calling in' of long range weapons from 'forward observers' onto designated regions.

Appendix B: EINSTein Entity Definition Boxes





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19. ABSTRACT

In order to support its continuous modernisation process, the Australian Army requires analytical support in determining the effectiveness of their conceptual Enhanced Combat Force (set fifteen years ahead). Central to this is how new and emerging technologies might impact on how the land force operates, and, consequentially, how the Army's operational concepts might need to change. Agent Based Distillations (ABD) have been employed to analyse a problem based on Manoeuvre Operations in a Littoral Environment concept. Specifically, the hypothesis tested was whether a small, mobile force with high situational awareness coupled with effective reach-back munitions could defeat a significantly larger force. This paper illustrates the application of one such ABD, EINSTein, in support of the analysis of this hypothesis, and highlights the potential utility of ABDs for land operations analyses.

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